Percutaneous Repair Method and Achilles Tendon Rupture Rehabilitation

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Abstract

Background: Subcutaneous, spontaneous, complete ruptures of the Achilles tendon are usually caused indirectly by trauma associated with rapid movement. When minimally invasive Achilles tendon repair is performed, an active rehabilitation protocol can be implemented that allows for fast, measurable progress, reduced tissue atrophy, and an improved range of motion, thereby reducing pain and increasing patients' overall physical well-being. However, overestimating the effectiveness of rehabilitative interventions can lead to arbitrary advancements in rehabilitation that significantly exceed the permitted levels of daily or professional activity. This issue can lead to various side effects and slow rehabilitation. The aim of the study was to evaluate the influence of adverse effects on objective outcomes after minimally invasive Achilles tendon repair.

Methods: The study included 36 individuals with complete Achilles tendon rupture who underwent the percutaneous Ma-Griffith technique. The same rehabilitation protocol was used.

Results: Five side effects were identified during rehabilitation: deformation of the repair construct (DRC), irritation of the sural nerve (SNI), morning ankle stiffness (MAS), edema of the soft tissue around the tendon (OST) and suture knots. DRC and MAS were associated with a longer time being required to achieve full ankle range of motion. SNI and OST were associated with a longer time being required to meet the criteria for dynamic training. None of the side effects were related to the isokinetic strength of the ankle plantar and dorsiflexors.

Conclusions: The incidence of the assessed side effects in the postoperative period is not related to the type of activity, whether it is professional or amateur. Among the identified side effects, deformation of the regenerated shape of the heel tendon and MAS cause a delay in the recovery of full ankle range of motion. Calf nerve irritation and soft tissue swelling increase the time it takes to meet the criteria for starting dynamic training.

Trial registration:

The study was approved by the ethics committee of the Academy of Physical Education in Katowice (no. 13/2007)

Background

The optimal treatment choice for an Achilles tendon rupture is controversial [1, 2]. The currently used methods of treatment include nonsurgical (conservative) treatment and surgical treatment, and the surgical methods are considered either traditional (open method with or without anastomosis strengthening) or closed (percutaneous suturing method) [3-6].

The broadly accepted view is that the open method is superior to conservative treatment because it is associated with a lower risk of secondary rupture (rerupture) of the Achilles tendon, but it is associated with a higher risk of local complications (even 20-fold higher) [4, 6]. However, authors have reported inconsistent results regarding the complications associated with "open" surgery. Some have reported a high overall complication rate, while others have observed a lower rate, including a low incidence of tendon rupture [6, 7]. Moreover, nonsurgical treatment is associated with a higher risk of subsequent heel tendon rupture and weakening of the lower leg muscles [8].

In this context, the method with which percutaneous repair of a ruptured Achilles tendon is performed might be considered a good compromise between traditional open surgery and conservative management [9, 10]. In the literature, in addition to the percutaneous method, a minimally invasive technique has been described. There are no exact definitions for the two methods, i.e., the percutaneous and minimally invasive methods [3]. According to Carmont et al. [3], the main difference is that the percutaneous method lacks visual control for the apposition of the tendon stumps, although visual control can be gained using additional tools including ultrasound or intraoperative endoscopy. The disadvantage of endoscopy is that the local posttraumatic hematoma is drained, which is considered vital for healing [11].

The percutaneous suturing of a ruptured Achilles tendon was first described was in 1977 by Ma and Griffith [12]. By definition, as it is a closed method, it minimizes the risk of infection. On the other hand, it is associated with a risk of intraoperative calf nerve injury and tendon rerupture [13]. The mechanical strength of the anastomosis obtained in this way has been questioned [14].

The results of the research showed that surgical treatment enables a faster return to work and sports after heel tendon rupture than does conservative treatment [15]. However, many of the current review studies have shown that there are no significant differences in the subjective results or range of motion of the limb between the types of treatment (surgical or conservative) [15, 16]. Therefore, some authors are inclined to choose open and percutaneous techniques, which yield results similar to those of conservative treatment but significantly reduce the risk of repeated tendon rupture [16, 17].

In general, a large variety of functional rehabilitation schemes have been used in studies in the literature. The differences mainly relate to when it is possible to subject the operated limb to full weight-bearing loads, how long the brace should be worn, which position the foot and ankle should be placed in initially, and whether to allow active exercises that extend the range of motion in the ankle while the individual is wearing the brace [18]. Choosing the type of postoperative management, similar to choosing the method of repair treatment, may be dictated by the level of physical activity of the person undergoing the operation. For athletes, functional rehabilitation seems to be a key factor in shortening the period of a player's absence [19]. Individuals return to sports activity after the complete rupture of the Achilles tendon after an average of 3 to 11 months; sometimes, recovery takes longer, and the duration depends on the method of treatment [20, 21]. Among physically active people, especially professional athletes, the shortest period of ankle immobilization that safety allows is preferred [22].

The aim of the study was to evaluate the influence of adverse effects on objective outcomes after minimally invasive Achilles tendon repair.

Methods

The analysis included 36 people (33 men and 3 women) with acute (up to 14 days after injury), spontaneous, subcutaneous and complete ruptures of the Achilles tendon [23]. The average age of all the patients was 40.1 ± 11.3 years (23-72 years), that of the men was 39.1±10.1 years (23-61 years), and that of the women was 50.7 ± 20.6 years (31-72 years). Fourteen subjects reported Achilles tendon pain prior to its rupture. In 26 men, the Achilles tendon ruptured during sports activities, while in 7 men and 3 women, it ruptured during daily (nonsport) activities. Among the subjects who were injured during sports activities (n = 26), 10 were professional athletes and 16 practiced recreational sports, as classified by the American Heart Association and the American College of Sports Medicine.

Achilles tendon rupture was confirmed by ultrasound imaging. The exclusion criteria included steroid injections, orthopedic surgery of the spine and lower extremities, and neurological or rheumatological conditions affecting joint function or muscle tone. The study was conducted at Galen-Orthopaedics and Fizjofit-Galen in Bieruń from September 2009 to January 2012.

The Achilles tendon was sutured in accordance with the Ma-Griffith method [12], and a rehabilitation protocol was implemented (from the first day after surgery) for 164.1 ± 53.3 days, with visits occurring at least every two weeks (Table 1). After surgery, the foot was placed in 45° of plantar flexion in a ROM-Walker orthosis (7.5° angular displacement). The angle of dorsiflexion of the ankle was increased from the 2nd week after the surgery by 7.5°-15° every 7-14 days, achieving a neutral position by 6 weeks after the surgery.

Table 1
Stages of postoperative rehabilitation

Time from surgery	Rehabilitation indications	Therapeutic goals
1-2 weeks	· exercises to maintain the range of motion of the knee and hip · isometric exercises for the pelvic girdle and lower limb · active toe movements · core stability exercises in the "lying down" position · frequent elevation of the operated limb (above the hip line) · no loading the operated limb with body weight · learning to walk with crutches · continued immobilization of the operated limb	· prevention of muscle atrophy in the operated lower limb · maintaining the normal range of motion of the hip and knee in the lower limb affected by dysfunction · prevention of postoperative complications (including deep vein thrombosis) · swelling and pain control · protection of operated tissues
2-5/6 weeks	· gradual loading of the operated limb in the orthosis - walking should be performed by the rolling technique, starting from heel contact with the ground so that there is pressure only on the rear part of foot during standing · active dorsiflexion and plantar flexion of the ankle and circular movements with the foot in a painless range of motion (exercises without orthosis) · introduction of and the progressing increase in loads during plantar flexion and dorsiflexion using an elastic band with low/medium resistance at 3 weeks after surgery · active exercises to increase the strength and endurance of the muscles of the operated lower limb · introduction of a stationary bike · start of soft tissue therapy on the operated area at 2 weeks after surgery · continuing the recommendations from the previous stage of rehabilitation · progressive loading of the operated limb using a dynamographic platform · work on gait reeducation (gradual crutches withdrawal) and correct foot propulsion · elements of manual therapy with a focus on improving the range of ankle joint mobility · stretching (passive and active) of the muscles of the operated limb · improving the muscular strength of the lower limb muscles with the use of body weight load (rising up on the foot)	· walk with crutches and orthosis · increasing the active range of ankle motion in the operated limb · increasing the strength of the leg and foot muscles · creating conditions for eccentric work in the triceps surae · maintaining and increasing the overall strength (bicycle ergometer · improving the elasticity of postoperative scars and the Achilles tendon itself and preventing adhesions · withdrawal of the orthosis · achieving the ability to fully load the operated limb · restoring smooth and symmetrical gait · making postoperative scars and the Achilles tendon more flexible · obtaining full active mobility of the ankle of the operated limb · increasing the strength of the lower limb muscles
9-11	· continuing the previous rehabilitation exercises	· making postoperative scars and the Achilles tendon more

weeks	· continuing to improve the strength of the lower limb muscles (mainly the plantar flexors of the ankle) - (rising up on the foot)	flexible · increasing the strength of the lower limb muscles obtaining the ability to make the foot rise up
12-14/16 weeks	· introducing dynamic training · first assessment of the objective parameters	· performing a symmetrical jump on the feet · running properly on the treadmill · asymmetry decreases during an objective study · controlling the effects of rehabilitation
14/16-18/20 weeks	· dynamic training based on elements specific to the sport practiced by the patient (specialist training) · second assessment of the objective parameters	· full recovery and compensation of existing discrepancies between the two lower limbs · controlling the effects of rehabilitation

Deformation of the repair construct (DRC) of the Achilles tendon was diagnosed clinically (visually and by palpation) with the use of ultrasound between 6 and 8 weeks after surgery. These deformations were considered to be a disruption of the linear course of the scar at the suture, with thickening (> 30% relative to the tendon of the nonoperated limb) and irregular remodeling in the long axis for at least 6 cm, without any signs of adhesion with surrounding tissues.

Irritation of the sural nerve (SNI) was diagnosed as paresthesia in the area of its innervation at the height of the lateral ankle and below the lateral edge of the foot (no abnormalities were found before surgery).

Morning ankle stiffness (MAS) was considered to be a feeling of tension and a limitation in foot movement stemming from the Achilles tendon and lasting for more than 30 minutes after waking up [24].

Edema of the soft tissue around the tendon (OST) was defined as a reversible deformation of the operated segment disrupting the contour of the medial and lateral ankle.

Suture knot symptoms were defined as subcutaneous irritation of the surrounding soft tissues by surgical threads remaining after the heel tendon was sutured.

The first objective evaluation of the treatment effects was carried out during the period of introducing dynamic training. The height of a single-toe raise was assessed by measuring the distance from the ground to the maximum plantar flexion of the calcaneal tubercle. The measurements were also taken at the end of rehabilitation. The final result was the average difference between the operated and nonoperated limbs.

The stability test was carried out on a mobile platform with Balance System SD (BIODEX®, New York, NY, USA) and included 5 repetitions lasting 20 seconds each, with a 30-second break between repetitions, and the degree of instability was 10 (a value of 1 corresponds to the least stable platform and a value 12 corresponds to the most stable platform). The test was performed at the time dynamic training was introduced and at the end of rehabilitation. The results are presented in the form of stability indexes: the anterior-posterior stability index (APSI), the medial-lateral stability index (MLSI) and the overall stability index (OSI). The indicators were calculated according to the following formulas:

$$OSI = \sqrt{\frac{\Sigma(0-X)^2+\Sigma(0-Y)^2}{n}} \quad MLSI = \sqrt{\frac{\Sigma(0-X)^2}{n}} \; APSI = \sqrt{\frac{\Sigma(0-Y)^2}{n}}$$

where X is the platform deviation value in the x axis, Y is the platform deviation value in the y axis, and n is the number of observations during one test.

Isokinetic strength was measured with a dynamometer with the Primus RS isokinetic evaluation kit (BTE Technologies Inc., Hanover, Maryland, USA). The test was performed at the end of rehabilitation. The test was carried out according to a strictly defined procedure, which included: verbal instructions explaining how to perform the test, warm-up, trial test at a certain speed of movement, rest between tests and the proper test with measurement. Each subject performed a 10-minute warm-up, which included: riding on a bicycle ergometer, exercises in the field of dynamic stretching including balance positions, exercises increasing the range of joint motion and improving the flexibility of soft tissues, and elements of central stabilization. During the test, the subject laid face down with the knee joint extended and the foot of the examined limb supported and stabilized. The lower left limb was assessed first. The starting position was maximum dorsiflexion of the ankle, and the final position was 50° of plantar flexion. First, the subject performed 5 plantar flexion movements and 5 dorsiflexion movements in a given range of motion at an angular velocity of 120°/s, and then, after 60 seconds, repeated the test at an angular velocity of 60°/s. The first attempt was performed as an introduction and the subject was informed about the mistakes made. The second attempt at an angular velocity of 60°/s was the measurement test. Both trials were performed once, separately for the left and right lower limbs.. The isokinetic evaluation was performed under concentric conditions.

All statistical analyses were performed using Statistica software (release 10.0, StatSoft, Tulsa, OK, USA). The qualitative variables were compared using the c^2 test or Fisher's test. The impacts of the treatment and side effects on the progression of rehabilitation were assessed using Student's t-test. The associations between the variables and the tested parameters were assessed by Pearson's correlation or Student's t-test. The significance level was set to be $p < 0.05$.

The study was approved by the local ethics committee of the Academy of Physical Education, under agreement number 13/2007. All individuals who participated in the study gave their informed, written consent.

Results

The most common side effect was DRC, which occurred in 16.7% of the participants. The second most common symptoms were SNI, which occurred in 11.1% of the participants, and MAS, which occurred in 11.1%. OST occurred in 8.3% of the participants, and suture knots rather than sewing occurred in 5.6%.

In summary, various side effects were observed in 10 (27.8%) subjects (9 men and 1 woman; mean age: 40.9 ± 11.3 years). In the remaining 26 (72.2%) subjects (age: 39.7 ± 11.5 years), no abnormalities (side effects) were observed in the postoperative period.

Deformation of the repair construct

Of the 14 men who reported Achilles tendon pain prior to its rupture, 42.9% exhibited DRC. In the remaining patients (n = 22), who did not report any prior pain, DRC was not observed ($c^2 = 11.3$, $p = 0.002$).

In persons diagnosed with DRC, compared to those treated without DRC, the BMI value and the frequency of reported tendon pain prior to injury were significantly higher (Table 2). There were no significant differences in age, sex, location of injury, type of physical activity, or percentage of people practicing sports at the professional level (Table 2).

Table 2
Characteristics of patients with deformation of the repair construct

	DRC (+) n=6	DRC (-) n=30	p
Age (years)	45,8±9,5	38,9±11,4	0,172
Side (right/left)	3/3	14/16	1,000
Sex (male/female)	6/0	27/3	1,000
BMI (kg/m^2)	30,3±1,7	27,3±2,9	0,024
Tendon pain before rupture (yes/no)	6/0	8/22	0,002
Physical activity (sports/daily)	4/2	22/8	1,000
Professional sport activity (yes/no)	1/5	9/21	0,655

Irritation of the sural nerve

SNI occurred in 11.1% of the participants within 4-6 weeks after surgery during the gradual withdrawal of the stabilizing orthosis and gradual return to weight-bearing on the operated limb (Table 3). In terms of age, sex, BMI, location of damage, history of pain, type of physical activity and type of sport activity, there were no significant differences between the groups with SNI and without SNI (Table 3).

Table 3
Characteristics of patients with irritation of the sural nerve

	SNI (+) n=4	SNI (-) n=32	p
Age (years)	46,8±10,5	39,2±11,2	0,212
Side (right/left)	3/1	14/18	0,326
Sex (male/female)	3/1	20/2	0,305
BMI (kg/m^2)	29,1±2,9	27,7±3,0	0,390
Tendon pain before rupture (yes/no)	2/2	12/20	0,634
Physical activity (sports/daily)	2/2	24/8	0,305
Professional sport activity (yes/no)	1/3	9/23	1,000

Morning ankle stiffness

Persons with MAS and those free of this symptom did not differ significantly in terms of the analyzed characteristics (Table 4), except for the frequency of pain in the heel tendon before its rupture. Of the 14 rehabilitated men who reported Achilles tendon pain prior to rupture, 28.6% reported morning stiffness, while in those with no history of tendon pain (n = 22), ankle stiffness was not observed (c^2 = 7, 1, p = 0.017).

Table 4
Characteristics of patients with morning ankle stiffness

	MAS(+) n=4	MAS(-) n=32	p
Age (years)	49,0±6,9	38,9±11,3	0,093
Side (right/left)	2/2	15/17	1,000
Sex (male/female)	4/0	29/3	1,000
BMI (kg/m^2)	30,1±1,6	27,5±2,9	0,109
Tendon pain before rupture (yes/no)	4/0	10/22	0,017
Physical activity (sports/daily)	2/2	24/8	0,305
Professional sport activity (yes/no)	0/4	10/22	0,559

Edema of the soft tissue around the tendon

OST symptoms around the Achilles tendon were present in only 3 men (Table 5). There were no differences between the patients with OST and those without OST (Table 5).

Table 5
Characteristics of patients with edema of soft tissue around the tendon

	OST (+) n=3	OST (-) n=33	p
Age (years)	46,0±12,8	39,5±11,2	0,347
Side (right/left)	3/0	14/19	0,095
Sex (male/female)	3/0	30/3	1,000
BMI (kg/m^2)	27,7±1,4	27,9±3,1	0,934
Tendon pain before rupture (yes/no)	2/1	12/21	0,547
Physical activity (sports/daily)	2/1	24/9	1,000
Professional sport activity (yes/no)	1/2	9/24	1,000

Suture knots

Postsurgical subcutaneous suture knots associated with irritation of the surrounding tissues were found in 2 subjects (5.6%). Therefore, this symptom was not taken into account as a factor in assessing the progression of rehabilitation or in assessing the relationships of side effects with objective parameters.

Coexistence of side effects

The most common side effects were DRC with MAS (n = 4; 66.7%) and SNI with OST (n = 3; 50%). None of the patients with a proper tendon regeneration contour showed concurrent MAS. None of the patients with proper nerve function in the calf experienced OST.

Impact of the side effects on the course of rehabilitation

Full range of motion in the ankle joint (53.2±15.9 days) (Table 6), as well as the ability to load the limb with full body weight (56.2±12.6 days) (Table 6), was achieved around the 8th week, while dynamic training started, on average, after week 15 (108.7±13.3 days).

Table 6
The impact of side effects on the course of rehabilitation

	Deformation of repair construct (DRC)		**Irritation of sural nerve (SNI)**		**Morning ankle stiffness (MAS)**		**Edema of soft tissue around tendon (OST)**	
	Yes	No	Yes	No	Yes	No	Yes	No
Static contraction training (days)	31.0± 8.4	37.1± 10.5	31.8± 4.6	36.6± 10.8	29.8± 9.9	36.8± 10.3	31.0± 5.3	36.5± 10.6
Full range of motion (days)	67.5± 20.0	50.2± 13.5*	50.5± 28.4	53.5± 14.3	77.3± 13.3	50.0± 13.5†	52.3± 34.4	53.3± 14.2
Full limb load (days)	52.8± 13.8	56.9± 12.5	56.5± 22.9	56.2± 11.3	56.8± 13.7	56.1± 12.7	47.7± 17.8	57.0± 12.1
Dynamic training (days)	114.7± 13.6	107.4± 13.1	125.0± 4.1	106.5±1 2.6†	112.3± 16.1	108.2± 13.1	124.3± 4.7	107.2± 12.9*
Yes – symptom occurs, No – no symptoms; †p<0,01 (Yes versus No); * p<0,05 (Yes versus No)								

The presence of DRC and MAS significantly increased the time needed to achieve full range of motion in the ankle joint (by 17 and 27 days, respectively) (Table 6). DRC and MAS, on the other hand, were not related to the time at which resistance training was introduced, the time at which the ability to fully load the operated limb was achieved, or the time at which dynamic training began.

In turn, SNI and OST were associated with a longer time being needed to meet the criteria for starting dynamic training (by approx. 18 and 17 days, respectively) (Table 6). However, there was no relationship between these symptoms and the time when the resistance training started, when full range of motion in the ankle was achieved, or when the ability to fully load the operated limb was achieved. Achilles tendon pain being present before its rupture extended the time needed to achieve full range of motion in the ankle joint by approximately 14 days (61.9 days vs. 47.4 days, p = 0.006). In the analysis of covariance, the occurrence of tendon pain before its injury as well as BMI and age were included. After taking into account the abovementioned variables, the relationship between both SNI and OST and the time of starting dynamic training remained statistically significant. Subjects with calf nerve dysfunction started dynamic training approximately 17 days later than did those without signs of nerve irritation (125 days vs. 108 days, p_{adj} = 0.018).

Subjects who experienced OST also started dynamic training approximately 14 days later, on average, than did those who did not have edema during rehabilitation (123 vs. 109 days, p_{adj} = 0.032).

Regarding the covariance analysis, the time needed to achieve full range of ankle joint mobility could not be compared with respect to DRC or MAS. All subjects with DRC and MAS had pain before the injury, which resulted in a so-called ‘incomplete system’, in which there were no people with DRC or MAS who did not report previously experiencing Achilles tendon pain.

Impact of side effects on objective outcomes of treatment

The objective parameters were assessed twice. The first analysis was performed when the criteria for starting dynamic training were met, and the second analysis was performed after the rehabilitation program was completed. Only the study on the isokinetic strength of the plantar flexion and dorsiflexion muscles of the foot was carried out once after the postoperative rehabilitation program was completed (Table 7). For stability indicators and isokinetic strength, interlimb comparisons, in which the results on the nonoperated side (NOP) were compared with those on the operated side (OP), were performed.

Table 7
Heel-raise, stability indexes and muscle strength - comparisons between the two limbs and the two studies

	Dynamic training (D)		**The end of rehabilitation (R)**	
	Nonoperated leg (NOP)	Operated leg (OP)	Nonoperated leg (NOP)	Operated leg (OP)
Heel-raise (cm)	3.1±1.0		0.9±0.7‡	
OSI	4.5±1.6	5.0±2.0*	4.6±1.5	5.2±2.6
APSI	3.1±1.2	3.4±1.4	3.5±1.1	3.8±2.1
MLSI	2.6±1.1	2.9±1.1	2.3±0.9	2.7±1.4†
60°Z (N)	-	-	665±142	633±131*
60°P (N)	-	-	223±46	223±52

* NOP versus OP, p<0,05; † D versus R, p<0,01;‡ D versus R, p<0,001; OSI – overall stability index; APSI – anteroposterior stability index; MLSI – mediolateral stability index; 60°Z – isokinetic strength of the plantar flexor muscles at an angular velocity of 60 degrees/s; 60°P – isokinetic strength of the dorsiflexor muscles at an angular velocity of 60 degrees/s

The difference in the heel lift height between the NOP and OP limbs was significantly larger at the first evaluation than at the end of rehabilitation (3.1±1.0 vs. 0.9±0.7, $p < 0.001$). In the interlimb comparisons (Table 7; NOP vs. OP), significant differences were observed for the OSI during dynamic training and for the maximum isokinetic strength of the muscles during plantar flexion at an angular velocity of 60°/s (60°Z). The OSI value on the NOP side was significantly lower than that on the OP side (4.5±1.6 vs. 5.0±2.0, $p = 0.039$), while the isokinetic strength of the flexor muscles of the foot on the NOP side was significantly higher than that on the OP limb (665±142 vs. 633±131, $p = 0.037$). The values of the other two stability indicators, i.e., APSI and MLSI, did not differ among the studied groups during the first (dynamic training) or second (end of rehabilitation) assessment. There was also no significant difference between the extremities in isokinetic strength during dorsiflexion (60°P).

No significant differences were found between the values of the parameters measured at the beginning of dynamic training and those measured after rehabilitation (Table 7; D vs. R), except for MLSI on the NOP side, whose value was higher in the first assessment ($p = 0.007$).

Table 8 presents the results of the analysis of the relationship between the occurrence of side effects during the rehabilitation program and the function of the musculo-tendon unit, as assessed using the abovementioned parameters, i.e., heel-lift height, stability indicators and the isokinetic strength of the plantar flexors and dorsiflexors of the foot. In this analysis, the stability indicators and muscle isokinetic strength were expressed as the difference between the NOP and OP limbs.

Table 8
Heel-raise, stability indexes and maximum isokinetic strength stratified by the side effects

		Dynamic training				**The end of rehabilitation**					
		Heel-raise (cm)[a]	Stability indexes[a]			Heel-raise (cm)[a]	Stability indexes[a]			Maximum isokinetic strength (N)[a]	
			OSI	APSI	MLSI		OSI	APSI	MLSI	60°Z	60°P
Deformation of repair construct	Yes	4.2±0.2	-1.5±0.7	-0.9±0.7	-0.7±1.1	1.7±0.2	-2.5±1.6	-2.2±0.6	-1.5±1.4	47±88	2±96
	No	2.9±0.9	-0.3±1.4	-0.2±0.9	-0.2±1.1	0.7±0.6	0.1±1.5	0.2±1.2	-0.1±0.9	28±72	-1±46
	p	0.001	0.059	0.086	0.340	0.0008	0.002	0.0001	0.007	0.589	0.918
Irritation of sural nerve	Yes	4.1±0.4	-1.9±0.4	-1.1±0.5	-0.6±0.5	1.6±0.6	-2.4±2.0	-1.6±1.1	-1.1±2.1	45±69	-9±54
	No	3.0±0.9	-0.3±1.3	-0.2±0.9	-0.2±1.2	0.8±0.6	-0.2±1.6	-0.1±1.5	-0.3±1.0	30±77	2±61
	p	0.022	0.023	0.089	0.484	0.029	0.022	0.071	0.250	0.716	0.760
Edema of soft tissue around tendon	Yes	4.0±0.2	-1.9±0.4	-0.9±0.3	-0.8±0.3	1.4±0.6	-2.9±2.1	-1.6±1.3	-1.6±2.2	14±38	-9±67
	No	3.0±1.0	-0.4±1.3	-0.3±0.9	-0.2±1.2	0.9±0.6	-0.2±1.6	-0.2±1.5	-0.3±1.0	35±79	1±59
	p	0.106	0.049	0.300	0.353	0.183	0.011	0.131	0.055	0.665	0.779
Morning ankle stiffness	Yes	4.3±0.1	-1.2±0.8	-0.7±0.7	-0.8±1.4	1.8±0.2	-1.7±0.9	-1.9±0.5	-0.7±0.5	87±82	-40±84
	No	3.0±0.9	-0.4±1.4	-0.2±0.9	-0.2±1.1	0.8±0.6	-0.3±1.9	-0.1±1.4	-0.4±1.3	22±71	7±53
	p	0.009	0.286	0.365	0.325	0.004	0.179	0.020	0.579	0.116	0.143

[a] the result expressed in the form of the mean value and standard deviation of the difference between the nonoperated leg and the operated leg; OSI – overall stability index; APSI – anteroposterior stability index; MLSI – mediolateral stability index; 60°Z – isokinetic strength of the plantar flexor muscles at an angular velocity of 60 degrees/s; 60°P – isokinetic strength of the dorsiflexor muscles at an angular velocity of 60 degrees/s

The difference in the heel lift height was significantly larger in individuals with current DRC than in those without DRC, in both the first (4.2±0.2 vs. 2.9±0.9, p = 0.001) and second assessments (1.7± 0.2 vs. 0.7±0.6, p = 0.0008). In the second study only, a significant relationship was also observed between this side effect and all indicators of stability. The differences in the values of the stability indicators between the NOP and OP sides were significantly larger (absolute terms) in patients with DRC than in those without DRC: -2.5±1.6 vs. 0.1±1.5 (p=0.002), -2.2±0.6 vs. 0.2±1.2 (p=0.0001), -1.5±1.4 vs. -0.1±0.9 (p=0.007) for OSI, APSI and MLSI, respectively.

In both evaluations, the presence or absence of SNI was significantly related to the heel lift height and OSI. The difference in the heel lift height between the NOP and OP limbs was significantly larger in subjects with SNI than in subjects without this side effect in the first (4.1±0.4 vs. 3.0±0.9, p = 0.022) as well as the second assessment (1.6±0.6 vs. 0.8±0.6, p = 0.029). The absolute value of the difference in the OSI between the NOP and OP limbs was larger in the subjects with SNI than in those without SNI in the first (-1.9±0.4 vs. -0.3±1.3, p = 0.023) and second evaluations (-2.4 ±2.0 vs. -0.2±1.6, p = 0.022).

MAS was associated with the heel lift height (both studies) and OSI (only the second study). The difference in the heel lift height between the limbs was larger (absolute values) in the subjects with current MAS: 4.3±0.1 vs. 3.0±0.9 (p = 0.009), 1.8±0.2 vs. 0.8±0.6 (0.004) at the beginning of dynamic training and at the end of rehabilitation, respectively. The difference in the APSI between the NOP and OP sides was larger (absolute terms) in the subjects with MAS than in those without this side effect in the second examination (-1.9±0.5 vs. -0.1±1.4, p = 0.020).

OST was significantly associated with the OSI in both studies. The difference in the OSI between the NOP and OP sides was larger in the subjects with OST in the first (-1.9±0.4 vs. -0.4±1.3, p = 0.049) and second studies (-2.9± 2.1 vs. -0.2±1.6, p = 0.011).

None of the side effects were associated with the isokinetic strength of the plantar flexors or dorsiflexors of the ankle.

Considering that the results obtained in the objective studies could have been affected by additional factors, a multifactorial analysis was also carried out. Before the multifactorial analysis was performed, to identify factors that might affect the objective parameters, associations between the objective parameters and the following features were examined: age, sex, BMI, the operated leg (right/left), whether pain occurred before the injury, type of physical activity (sports, daily) and the type of sport activity (professional, recreational) (Table 9).

Table 9
Relationship between the objective indicators of the tendon functional assessment and the examined features

	Dynamic training				**The end of rehabilitation**					
	Heel-raise (cm)[a]	Stability indexes[a]			Heel-raise (cm)[a]	Stability indexes[a]			Maximum isokinetic strength (N)[a]	
		OSI	APSI	MLSI		OSI	APSI	MLSI	60°Z	60°P
Age	ns	ns	ns	ns	ns	ns	0,012[b]	ns	ns	ns
Sex	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
BMI	0,00023[b]	ns	ns	ns	0,0001[b]	0,008[b]	0,0004[b]	ns	ns	ns
Operated leg	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
Tendon pain before rupture	0,011[c]	ns	ns	ns	ns	0,001[c]	<0,0001[c]	0,033[c]	ns	ns
Physical activity	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
Sport activity	0,010[c]	ns	ns	ns	0,038[c]	ns	ns	ns	ns	ns

ns – non-significant, [b] p-value for Pearson's correlation coefficient; [c] p-value for t-test; objective indicators of the tendon functional assessment are expressed as the difference between the nonoperated leg and the operated leg; OSI – overall stability index; APSI – anteroposterior stability index; MLSI – mediolateral stability index; 60°Z – isokinetic strength of the plantar flexor muscles at an angular velocity of 60 degrees/s; 60°P – isokinetic strength of the dorsiflexor muscles at an angular velocity of 60 degrees/s; Physical activity: athletic *versus* daily; Sport activity: professional *versus* recreational

At the start of dynamic training, the difference in the heel lift height between the limbs was significantly related to BMI, tendon pain before rupture and the type of sport activity. In professional athletes, the discrepancy in the heel lift height between the limbs was significantly lower than in those who were not athletes (2.4±1.1 vs. 3.4±0.8, $p = 0.010$). In the first study, none of the stability indicators (OSI, APSI, MLSI) were associated with the parameters studied.

After rehabilitation, a significant relationship was observed between the difference in the heel lift height and BMI and the type of sport activity. As in the first study, the professional athletes exhibited a smaller difference in the heel height between the NOP and OP limbs (0.5±0.6 vs. 1. ±0.6, $p = 0.038$).

In the second study, all stability indexes (OSI, APSI, MLSI) were significantly associated with pain before tendon rupture. In addition, the OSI and APSI were correlated with BMI and the APSI was correlated with the age of the subjects.

In the multifactorial analysis (multiple regression), the associations of the observed side effects with the heel lift height were taken into account, and the following variables were included: BMI, Achilles tendon pain before rupture and the type of sport activity in the first examination and BMI and type of sport activity in the second examination. The associations of the side effects and stability indicators assessed at the end of rehabilitation were also examined: for the OSI, BMI and pain before heel tendon rupture; for the APSI, BMI, pain before rupture, and age; and for MLSI, pain before rupture.

In the first evaluation (start of dynamic training), the multiple regression (BMI, pain before rupture, type of sport activity) showed that the difference in the heel lift height between the limbs was statistically significantly correlated with only the occurrence of SNI (regression coefficient b = 0.89, p = 0.007). The relationship between DRC (p = 0.132) and MAS (p = 0.342) in the multivariate analysis was nonsignificant.

In the second evaluation (end of rehabilitation), all the side effects that were significantly related to the height of the heel in one-way analysis, i.e., DRC, SNI, and MAS, remained significantly related to the height after the relevant corrections were taken into account (BMI, type of sport activity). After rehabilitation, DRC (regression coefficient b = 0.67, p = 0.003), SNI (regression coefficient b = 0.62, p = 0.014) and MAS (regression coefficient b = 0.68, p = 0.009) were associated with the difference in the heel lift height between the limbs, independent of the BMI and type of sport activity. DRC did not remain a significant factor associated with the stability parameters at the end of rehabilitation. In contrast to DRC, SNI (regression coefficient b = -1.64, p = 0.027) and OST (regression coefficient b = -2.09, p = 0.011) were independently associated with the OSI. In multivariate analysis, MAS was not associated with the APSI value.

The type of sport activity, independent of the other factors, was associated with a decrease in the heel lift height between the limbs, but this finding was observed only in the first study (dynamic training).

Discussion

Side effects

Similar to conservative treatment, percutaneous suturing of the Achilles tendon does not accurately restore the anatomical position of damaged fibers or guarantee the appropriate repositioning of the stumps remaining after tendon rupture [1, 3, 10]. On the other hand, with the remaining hematoma and primary regenerative local response serving as a foundation, function may be restored [25]. It is worth emphasizing that this is not the case with "open" sewing, during which the hematoma is flushed out and the effects of the immediate repair mechanisms are eliminated [26]. The fibers become aligned during the scar remodeling phase, i.e., at the beginning of resistance training, especially when the limb is loaded.

Excessive use of the operated limb leads to stretching of the soft connections between the stitched tendon stumps, which may result in secondary defense responses such as swelling along the Achilles tendon. According to the interviews, none of the subjects with DRC closely followed the recommendations of the physiotherapists. This low level of adherence mainly manifested in levels of daily and professional activity significantly exceeding the level that was recommended. The presence of deformities was statistically significantly associated with chronic pain having occurred before the rupture of the Achilles tendon. This finding indicates the presence of chronic tendinopathy and severe degenerative changes in the tendon. Apart from tendinopathy, the patient's weight may be important in the development of deformation. People with current DRC had a significantly higher body mass index than did those without DRC (30.3±1.7 vs. 27.3±2.9). However, these two groups did not differ in terms of the other parameters analyzed. In summary, the following important factors can lead to the deformation of the shape of the scar after surgery: a lack of full control of stump repositioning; chronic tendinopathy accompanied by degenerative changes and swelling of the Achilles tendon during overlapping, excessive, premature loading of the muscular-tendon unit and stretching; and excessive body weight.

Calf nerve injury is one of the complications of both open and percutaneous surgery [19]. It should be noted that intraoperative calf nerve damage occurs immediately after surgery, and sensory recovery in the nerve supply zone (if it occurs) is a slow process and can take approximately 6 months [27]. None of the operated patients reported sensory disturbances or other complaints in the area of its supply within 4 weeks after the surgery, during the period of no weight-bearing, during the use of the orthosis, or during the initial phase of rehabilitation. Therefore, the sensory disturbances in the calf nerve supply that occurred in 4 patients were not associated with intraoperative damage. The occurrence of symptoms was noted within 4–6 weeks after surgery, when the rehabilitated patients began to gradually load the operated limb with body weight.

MAS was observed in 11.1% of the subjects and was significantly associated with the occurrence of pain before the rupture of the Achilles tendon, suggesting the presence of tendinopathy. MAS concomitant with DRC was also found in the study population. Symptoms of ankle stiffness occurred in 4 out of 6 subjects with DRC. This deformation can weaken the elastomeric properties of the tendon and prevent it from moving smoothly. Percutaneous surgery allows the existing sliding tendon to be preserved [28]. Moreover, this type of surgery very rarely leads to adhesions around the tendon that can limit its mobility relative to the surrounding tissues.

OST occurred in 3 out of 4 subjects with SNI symptoms but did not occur among those who did not report SNI. It has been suggested that secondary defensive reactions in the form of edema along the Achilles tendon may cause pressure on the nerve at the point of contact with the tendon [29]. Symptoms of nerve dysfunction without soft tissue edema occurred in only one subject. This subject was the woman with the highest BMI in the whole group (33.1 kg/m2). The BMI value did not differ significantly with regard to the occurrence of SNI symptoms, but it could have been a predisposing factor for this symptom due to soft tissue overload in the operated zone.

Local tissue irritation associated with suture knots is caused by a defensive biological response to the foreign body, despite the total biocompatibility of the material used for sewing. The presence of internally palpable surgical thread nodes is a well-documented observation in percutaneous and open procedures [20]. However, this symptom has occurred incidentally in studies by other authors, and the removal of excess suture knots in another operation leads to its resolution [30].

The occurrence of side effects and complications may be associated with the type of rehabilitation method used after Achilles tendon injury. In recent years, an acceptable approach for the rehabilitation of Achilles tendon rupture has been identified, and the approach promotes immobilization with an orthosis, as well as early loading of the operated limb with limited ankle movement [31].

Rehabilitation progression and the impact of side effects on rehabilitation treatment

Rehabilitation after surgery within the heel tendon is a complex process for which no commonly accepted protocol has yet been developed [19]. Whether early full weight-bearing of the limb (within 1–2 weeks after surgery) should be permitted is an aspect of the protocol that has been debated [18, 31].

In this study, patients were not allowed to load the operated limb with body weight for the first 2 weeks. Additionally, active dorsiflexion and plantar flexion of the ankle and circular movements of the foot were introduced gradually at 2 weeks after the surgery. An important element of rehabilitation after Achilles tendon rupture is finding a "golden mean" between a period of immobilization that is too long and leads to many undesirable effects and one that is too short and can lead to secondary rupture of the tendon [32]. Maqurrian [5] believes that the rehabilitation protocol should take into account the surgical technique, in particular the type of suture used to connect the stumps of the ruptured tendon. Clanton et al. [33] noted that minimally invasive techniques for percutaneous repair is more likely to cause the tendon to stretch than is open treatment. The authors also suggest that percutaneous repair is associated with a risk of insufficient tendon capture. Ultimately, however, no significant differences in the strength of the tendon between the techniques used were found (open repair, the Achillon Achilles Tendon Suture System, the PARS Achilles Jig System and the Achilles Midsubstance Speed Bridge Repair variation) [33].

A high percentage of tendon rerupture (10%) after percutaneous sewing was observed in a study by Maes et al. [34]. The authors explained that these results were caused by allowing weight-bearing on the operated limb too early.

Lee et al. [14] analyzed the strength of three types of anastomoses: Krackow, reinforced Krackow and percutaneous anastomosis. The tendons were subjected to repeated and increasing loads (100, 190 and 369 N). Based on the results of these experiments, Lee et al. [14] do not recommend protocols introducing early full weight-bearing and early ankle movements.

The time at which resistance exercises and dynamic training should be introduced is also debatable. According to the rehabilitation protocol proposed by Gwynne-Jones et al. [35] and Doral et al. [27], resistance exercises should start after week 6; however, according to the program used in this study, they were started earlier, at an average of approximately 5 weeks after surgery (5, 1±1,5). For dynamic training, the abovementioned authors started this training as early as 10 weeks after surgery, while in this study, dynamic training began no sooner than 12 weeks postoperatively, after the following criteria were met: the subject was able to perform a single-toe raise on the operated limb and was able to walk independently and symmetrically.

Objective and subjective results of treatment

The Achilles tendon total rupture score (ATRS) [36] is a commonly used point scale for the subjective evaluation of the results of the treatment of complete Achilles tendon rupture, movement restrictions and their impact on physical activity [36].

While dynamometric muscle measurements are often used as indicators of tendon recovery after injury [37, 38], there are no reports on the use of stability or proprioception indicators for this purpose. In this work, three stability indicators (APSI, MLSI, OSI) were assessed. The obtained OSI results may indicate an improvement in deep sensation and proprioception in response to ongoing rehabilitation activities. This information is valuable because deep sensation disorders are considered one of the elements that is most difficult to restore to the preinjury state [39]. In turn, proprioception disorders are considered a predisposing factor for tendon damage in general [40]. In summary, the lack of significant differences in the OSI values between the OP and NOP limbs after rehabilitation treatment may indicate an improvement in deep sensation. On the other hand, from the beginning of dynamic training to the end of rehabilitation, there was no significant reduction in the OSI value on the operated side or on the healthy side.

In the study presented here, as in another publication [41], the strength of the planar flexor and dorsiflexor muscles was measured under isokinetic conditions at a speed of 60°/s. In both cases, no significant differences were observed in the maximum muscular strength of the dorsiflexors at the end of the rehabilitation period. Significantly lower values of strength were found, however, in the plantar flexors on the operated limb at the end of rehabilitation (on average 164 days from surgery) in this study and one year after surgery in the study by Syrek et al. [41].

The amount of data on the direct impact of postoperative complications on functional results is very limited. Therefore, one of the aims of this study was to investigate whether side effects slow rehabilitation. If so, we aimed to determine whether this effect translates into measurable changes in the objective parameters. To answer this question, we aimed to determine the impact of side effects on the heel lift height relative to the ground, stability indexes, and the isokinetic strength of the plantar flexors and dorsiflexors of the ankle. Multifactorial analysis showed a significant influence of all side effects, i.e., DRC, SNI, MAS and OST, on objective indicators.

DRC and MAS had a negative effect on the heel lift height, but this effect was observed only in the second examination (at the end of rehabilitation), while OST caused the OSI to worsen in both examinations. SNI had a similar effect on the difference in the heel lift height of the NOP and OP limbs in both studies. This symptom was associated with a worse OSI in both the first and second examinations.

The deficit in the muscular strength of the plantar flexors of the foot was not affected by the other side effects observed in the course of rehabilitation, i.e., DRC, MAS, and OST. The above symptoms slowed the course of rehabilitation, but there are no indications that they might decrease the muscular strength of the operated limb.

Side effects had a significant adverse effect on the heel lift height difference between the healthy and operated sides. Given that there is a correlation between isokinetic muscle strength and the heel lift endurance test result, a relationship of these symptoms with muscle strength should be expected. It has been suggested that a decrease in the heel lift height may be associated with the weakening of the muscles and/or lengthening of the operated tendon, but this relationship needs to be studied further [42].

A comprehensive analysis of the impact of multiple factors on spontaneous, subcutaneous, and complete heel tendon ruptures was proposed in a literature review, and considering our study, there is ongoing research on the optimal and permanent recovery of the function of the damaged area and improvement in the general physical condition of the people undergoing treatment.

Achilles tendon ruptures are more common in people who lead a sedentary lifestyle and take part in physically demanding activities in a sporadic and unprepared manner [43]. A way to reduce the number of Achilles tendon ruptures could be to inform individuals who are interested of the need for a gradual, appropriate increase in the level of physical activity and to be conscious of the dangers arising from sudden, rapid increases in the intensity of physical activity without proper preparation [44].

Conclusions

The incidence of the assessed side effects in the postoperative period is not related to the type of activity, whether it is professional or amateur. Among the identified side effects, deformation of the regenerated shape of the heel tendon and MAS cause a delay in the recovery of full ankle range of motion. Calf nerve irritation and soft tissue swelling increase the time it takes to meet the criteria for starting dynamic training.

The identified side effects have an adverse effect on the final outcome regarding the function of the damaged tendon: a) deformation of the regenerated shape of the heel tendon has a negative effect on the heel lift height on the operated limb side, b) calf nerve irritation negatively affects overall stability, c) MAS adversely affects the heel lift height on the operated side and stability in the sagittal plane, d) soft tissue swelling adversely affects overall stability.

Abbreviations

DRC – deformation of the repair construct

SNI – irritation of the sural nerve

MAS – morning ankle stiffness

OST – edema of the soft tissue around the tendon

ROM – range of motion

APSI – anterior-posterior stability index

MLSI – medial-lateral stability index

OSI – overall stability index

Declarations

Ethics approval and consent to participate

The study was approved by the local ethics committee of the Academy of Physical Education, under agreement number 13/2007. All individuals who participated in the study gave their informed, written consent.

Consent for publication

Not applicable.

Availability of data and materials

The datasets generated and analyzed during the current study are available from the corresponding author upon reasonable request.

Competing interests

The authors declare that they have no competing interest.

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Authors' contributions

KF conceived if the study, analyzed the collected data, and drafted the manuscript. PG and JR were involved in the validation and edition of the manuscript. KF and GH supervised the writing of the paper and gave final approval. All authors read and approved the final manuscript.

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